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Peculiarities of the applications of the two-probe AFM manipulator

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Experimental investigations of the electronic transport of the nanowires, nanotubes, and biological filaments are the essential point of the interest. The first experiments were done on ropes, but resent ones are performed on a single nano-object with attached metallic contacts and gates defined by e-beam lithography. Beside this, experiments focused on investigations of electronic transport through double wires structure or InAs nanowire junctions show a new physics in this type of devices. In the most cases an additional manipulations of the wires should be done to prepare such kind of structures.

Several approaches to manipulate the nanowires such as Si nano-tweezers, indium soldering technique, standard nano-probe manipulators incorporated in scanning electron microscopes or manipulations by atomic force microscope (AFM) probes are currently in use.

Two-probe AFM helps to make manipulations of the nanowires much more convenient. Besides home built devices, plenty multi-probe microscopes from leading companies are available today. Unfortunately, mentioned above designs are based on the idea of independent probes, in this case each probe is positioned by its own piezo-driver. But for manipulations of the nanowires the design with two semi-independent probes looks to have an essential advantage. In this configuration the main piezo-driver moves both probes and the auxiliary one defines mutual position of probes.

We present a simple two probes AFM manipulator with two individual feedback systems for each semi-independent probe [1]. The design of the AFM probe mounting allows to work with upright microscope with focal distance of 3 mm. Applications of manipulator and advantage of its two semi-independent probe design are presented as well and are in the focus of current report.

Both probes of the manipulator operate in the dynamic full-time contact AFM mode. The main idea of this mode is depicted in Figure 1. The top prong of the tuning fork oscillates in vertical direction as it is shown with two-arrows line. Two positions of the tip, namely, the topmost and the bottommost during the tuning fork oscillation cycle are shown in the picture. The tip end stays on the sample surface during the whole period of the tuning fork oscillation cycle due to the tip flexibility. Thus, this mode is actually a hybrid one, uniting the dynamic tapping and the contact AFM modes. Similar to the tapping mode the amplitude of the oscillations of the tuning fork is used as the feed back signal.

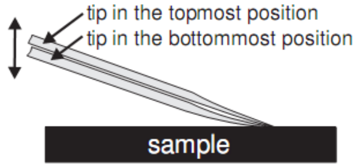

Figure 1. The main idea of the dynamic full-time contact AFM mode. The vertical two-arrows line is depicted the direction oscillations of the tuning fork top prong. Two positions of the tip, the the topmost and the bottommost during the tuning fork oscillation cycle are shown as well. The tip end stays on sample surface permanently due to the flexibility of the tip.

We use the level of the set point in this mode typically equal to 0.90-0.98 of the amplitude of free oscillations. Lower set point level means the higher pressure of the probe on surface and more pronounce bending of the probe. The set point level of 0.95 opens the ability to move the nanowires over substrate surface. The AFM mode used in manipulator is quite similar to standard contact AFM mode realized with cantilever. It is possible to apply this mode for the measurement of the friction forces of a bunch of InAs wires placed on SiO_2 surface [1]. Measured value of 50pN/nm is approximately 12.5 times larger than the previously reported experimental data [2]. Current measurement is done in ambient conditions and the water film on the sample surface must have influence on the measured friction forces.

Controlled tip-to surface interaction allows to scan nanowires at high set point value (0.98) and the nanowire with 100 nm diameter can be easily allocated [1]. Since the used mode tip constantly stays on the surface, the 100% duty cycle signal can be observe during the conductivity measurements of the metallic pads [2].

The transportation of the nanowire or the bunch of nanowires over substrate surface for dozens microns can be done just with one tip. But for the long-range transportation of big nanowire ($Bi_{1-x}Sb_x$ 400 nm diameter whisker) a more convenient way of the operation is to engage two probes of the manipulator. The advantage of the instrument two-probe design allows to use manipulator as two-prong fork to transfer wires with diameters of several hundreds nanometers (Fig. 2).

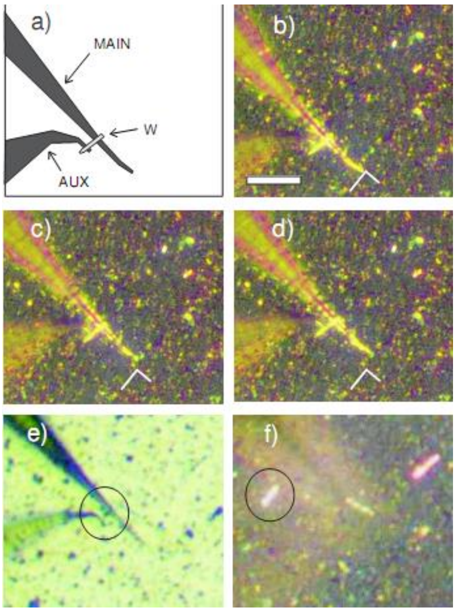

Figure 2. (a) The configuration of MAIN and AUX probes, and the BiSb wire (W) placed on them. (b)-(d) Short-ranged transportation of the wire, both tips stay on substrate surface, white angle points initial position of the MAIN tip end. (e) Both tips and the wire after long-ranged jump to a new position. The wire marked with a circle still lays on the tips. (f) The final position of the transported wire placed on the substrate and marked with a circle. (b)-(d), (f) In crossed polarized light. The horizontal scale bar in (b) corresponds to 10 m. The scale is the same for other four optical images.

So, we present the design of two probes AFM manipulator working together with short focal distance (3 mm) upright optical microscope. AFM of manipulator operates in dynamic full-time contact mode. This mode allows to control probe-to-surface force and to measure as the friction forces, so the conductivity similar to conventional contact AFM mode. Advantage of the instrument semi-independent two-probe design is presented as well.

1. A.A. Zhukov, V.S. Stolyarov, and O.V. Kononenko, *Review of Scientific Instruments* **88**, 063701 (2017).
2. G. Conache, (Lund & Halmstad), *Licentiate Thesis* (2008).